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THERMAL INKJET PRINTING HEAD

[Netsu inku jietto purinto heddo]

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Claims /1*

1. A thermal inkjet printing head characterized by the following facts: ink is locally heated in the thermal inkjet printing head, and bubbles are generated in the ink so that an ink droplet is formed from said ink; a nozzle hole is set in this thermal inkjet printing head and, together with it, an ink flow channel is set connected to said nozzle hole and allowing filling of said ink; and, in the space of said ink flow channel, a heating means is set at least whereby a portion extends in the space.

2. The thermal inkjet printing head described in Claim 1 characterized by the fact that said ink flow channel is formed between a base plate and a cover plate, said heating means is formed on said base plate and a selected portion of said base plate is etched off so that at least a portion of said heating means is separated from said base plate.

3. The thermal inkjet printing head described in Claim 2 characterized by the fact that said heating means has a heating part that is heated as current flows in it.

4. The thermal inkjet printing head described in Claim 3 characterized by the fact that said heating part is formed in a bridge shape.

5. The thermal inkjet printing head described in Claim 3 characterized by the fact that said heating part is formed in a cantilever shape.

6. The thermal inkjet printing head described in Claim 3 characterized by the fact that at least a portion of said heating part is formed in an H shape.

7. The thermal inkjet printing head described in Claim 3 characterized by the fact that at least a portion of said heating part is formed in a ring shape.

8. The thermal inkjet printing head described in Claim 3 characterized by the fact that said nozzle hole is formed through a prescribed site of said cover plate. /2

* [Numbers in right margin indicate pagination of the original text.]

9. The thermal inkjet printing head described in Claim 8 characterized by the fact that said heating part is aligned to said nozzle hole.

10. The thermal inkjet printing head described in Claim 8 characterized by the fact that said heating part is offset at least partially from said nozzle hole.

11. The thermal inkjet printing head described in Claim 3 characterized by the fact that said nozzle hole is set between said cover plate and said base plate.

12. The thermal inkjet printing head described in Claim 3 characterized by the fact that said nozzle hole is formed through a prescribed site of said base plate.

13. The thermal inkjet printing head described in Claim 12 characterized by the fact that said nozzle hole is formed in a tapered shape by means of anisotropic etching of said base plate.

14. The thermal inkjet printing head described in Claim 3 characterized by the fact that said heating means has a pair of lead parts connected to the two ends of said heating part, and said lead parts are attached to said base plate and, at the same time, said heating part has an electrical resistance substantially higher than that of said lead parts.

15. The thermal inkjet printing head described in Claim 14 characterized by the fact that said heating part and said lead parts are made of the same substance, and the cross-sectional area of said heating part is smaller than the cross-sectional area of said lead parts.

16. The thermal inkjet printing head described in any of Claims 1, 2, 3 and 14 characterized by the fact that an insulating layer is formed on said base plate, and the lead parts of said heating means are coated on said insulating layer.

17. The thermal inkjet printing head described in Claim 1 characterized by the fact that a temperature detecting means for measuring the temperature of said ink is set near said heating means.

18. The thermal inkjet printing head described in Claim 17 characterized by the fact that said heating means and said temperature detecting means substantially have the same constitution.

19. The thermal inkjet printing head described in Claim 2 characterized by the fact that a sealing plate having a prescribed hole formed through it is between said base plate and said base plate [sic, cover plate].

20. A thermal inkjet printing head characterized by the following facts: ink is locally heated in the thermal inkjet printing head, and bubbles are generated in the ink so that an ink droplet is formed from said ink; in this thermal inkjet printing head, a prescribed position of the base plate formed with an insulating layer coated on one surface is etched off from the side of the surface opposite said one surface and a diaphragm is formed by the selected portion of said insulating layer; a heating part is set on said diaphragm so that the heating means is attached to said insulating layer, and a cover plate is set separated from said insulating layer with a prescribed distance to form an ink flow channel, and, at the same time, a nozzle hole is formed through said cover plate, and, as ink in said ink flow channel is sprayed out from said nozzle hole, an ink droplet is generated.

21. The thermal inkjet printing head described in Claim 20 characterized by the following facts: joule heat is generated due to the flow of current in said heating part; said heating means has a pair of lead parts connected to the two ends of said heating part; and said lead parts are also attached to said insulating layer.

22. A thermal inkjet printing head characterized by the fact that it has the following parts: a base plate having a prescribed position etched off to form a recession on one surface, a first layer, which has a first linear expansion coefficient and is attached to said one surface, and has an extension portion that extends in a prescribed shape into the space above said recession, a second layer, which has a second linear expansion coefficient different from said first linear expansion coefficient and is attached to at

least said extension portion of said first layer, a cover plate, which is separated by a prescribed distance from the insulating layer of said base plate and has a nozzle hole formed through it, and a heating means, which at least heats said extension portion and bends said extension portion by means of the /3
difference between the first and second linear expansion coefficients.

23. The thermal inkjet printing head described in Claim 22 characterized by the fact that in said heating means, as current flows through said second layer, joule heat is generated in the heating part of said second layer.

24. The thermal inkjet printing head described in any of Claims 1, 2, 3 and 23 characterized by the fact that said first layer is made of a substance selected from Ta_2O_s, SiO_2, Si_2N_4, Al_2O_2, and the second layer is made of a substance selected from Ta, Ti, W, Cr, Ni, Mo, Pt, TaN_2, TiN, SiC, WC, NiCr, stainless steel, PtIr, and PtRh.

25. The thermal inkjet printing head described in Claim 24 characterized by the fact that said base plate is a monolayer or multiple layers made of substances selected from Si, W, Mo, Cr, Ni, NiCr, stainless steel and resins.

26. A thermal inkjet printing head characterized by the following facts: ink is locally heated in the thermal inkjet printing head, and bubbles are generated in the ink so that an ink droplet is formed from said ink; a nozzle hole is set in this thermal inkjet printing head, and, together with it, an ink flow channel is formed that is connected to said nozzle hole and allows filling of said ink; a heating means is set for locally heating the ink in said ink flow channel to generate bubbles; and said heating means has a heating part for growing said bubbles toward said nozzle hole.

27. The thermal inkjet printing head described in Claim 26 characterized by the fact that said heating part is set whereby it at least partially extends in the space in said ink flow channel.

Detailed explanation of the invention

Technical field

The present invention pertains to an inkjet printing head for use in inkjet printers, etc. More specifically, the present invention pertains to a thermal inkjet printing head that makes use of thermal energy as the driving source to generate ink droplets for printing.

Prior art

The thermal inkjet printer is well known. It is one type of the so-called on-demand inkjet printers. According to its operation principle, ink is locally heated to generate bubbles, and the exhaust volume by the bubbles generated in this case is used as the driving force to eject the ink from a nozzle hole to form an ink droplet for printing. Figure 1 is a schematic diagram illustrating a printing head used in a conventional thermal inkjet printer. As shown in the figure, ink flow channel (1) is formed on the printing head. Nozzle hole (1a) is formed on one end of the ink flow channel. The other end is connected to ink feeding path (2). Ink flow channel (1) is filled with ink (3). Usually, in nozzle hole (1a), ink (3) forms a meniscus due to surface tension. At the prescribed position on the wall that defines ink flow channel (1), heater (4) is formed. Here, instant heating leads to a film boiling on heater (1) [sic, (4)]. As a result, bubbles (5) are generated on heater (4). Consequently, due to the exhaust volume by generation of bubbles (5), ink (3) is partially pressed out from nozzle hole (1a), and said pressed-out portion (3a) then forms an ink droplet. Heating in this case is performed by applying a current pulse to heater (4) to generate joule heat. Consequently, after the pulse, heater (4) is quenched by ink (3) and the bubbles are extinguished, and fresh ink is fed into ink flow channel (1).

In this way, with this conventional thermal inkjet printing head, it is possible to perform on-demand printing. However, as heater (4) is on the wall of ink flow channel (1), heat generated by heater (4) is

dissipated due to thermal conduction to the main body of the head. Consequently, the heating efficiency of heater (4) is poor, and, when a pulse current is applied, the rise in temperature of heater (4) is relatively mild, so that sufficient film boiling cannot be performed. This is undesired. Also, as the thermal capacity of the main body is greater than that of heater (4), it takes a long time before heater /4
takes a long time before heater (4) rises to the prescribed temperature, so that not only is power consumption high, but also the thermal frequency response is slow, and the printing speed is thus limited. This is undesired, too.

Purpose

The purpose of the present invention is to solve the aforementioned problems of the prior art by providing a thermal inkjet printing head characterized by having both higher thermal efficiency and higher printing speed. Another purpose of the present invention is to provide a thermal inkjet printing head that allows easy manufacturing and is especially appropriate for high-density multinozzle structures.

Constitution

As a feature of the present invention, a heater is set in the ink flow channel formed in the printing head, so that the ink in the ink flow channel is locally heated to form bubbles. Said heater is formed such that it at least partially extends into the space of the ink flow channel, so that dissipation of heat from the heater to the printing head main body and base plate can be minimized. With said constitution, it is possible to minimize thermal conduction from the heater to the base plate. Consequently, it is possible to reduce the power consumption when it is heated to a prescribed temperature, while the thermal efficiency is improved. As a result, the printing speed can be increased significantly.

As another feature of the present invention, the heater is composed of two layers made of substances with different linear expansion coefficients. In this constitution, for example, when a current is applied to generate joule heat, the heater bends in the prescribed direction due to the difference in linear expansion coefficient of the layers. The kinetic energy of this bending movement is imparted to part of the ink. As a result, it is possible to form an ink droplet. In this case, when bubbles are generated due to heat from the heater, due to the exhaust volume caused by bubble generation and imparting of kinetic energy due to the bending movement of the heater, the ink droplet can be generated efficiently.

As yet another feature of the present invention, when a heater is set in the ink flow channel to generate bubbles, the bubbles gradually grow toward the nozzle hole according to the constitution. As a result, in the bubble growth assumption, the exhaust volume imparts kinetic energy to a portion of the ink toward the nozzle hole, so that the ink droplet can be generated efficiently. In this case, the heater may also be placed on the wall of the ink flow channel. However, it is preferred that it extend into the space of the ink flow channel.

In the following, an explanation will be given in more detail regarding the specific embodiment of the present invention with reference to the attached figures.

Figures 2 and 3 illustrate an application example of thermal inkjet printing head (10). As shown in the figure, thermal inkjet printing head (10) of the present invention has base plate (11). On one surface of base plate (11), a trench or recession (11a) is formed by means of anisotropic etching. It defines ink chamber (13). On the surface of base plate (11) where recession (11a) is formed, cover plate (12) is set at a prescribed distance. Although not shown in Figure 3, cover plate (12) has a spacer or sealing plate between cover plate (12) and base plate (11) so that the cover plate is positioned at a prescribed distance from base plate (11). Consequently, ink feeding channel (14) is formed between base plate (11) and cover plate (12). This ink feeding channel (14), together with ink chamber (13), forms the ink flow

channel. Consequently, ink chamber (13) and ink feeding channel (14) are usually filled with ink liquid (15). In this application example, nozzle hole (12a) is formed through the prescribed position of cover plate (12).

Heating part (16a) is set extending into the space in ink chamber (13). As can be seen from Figure 3, on the surface of base plate (11), ink chamber (13) in a nearly rectangular shape is formed as a recession, and heating part (16a) of heater element (16) is set in a bridge shape across said recession (13). In addition, a pair of lead parts (16b), (16b) connected to the two ends of heating part (16a) extend in the lateral direction. It is preferred that said heating part (16a) and lead parts (16b) be formed by attachment simultaneously using the same type of substance. However, as shown in the figure, the width of heating part (16a) is selected to be substantially narrower than the width of lead parts (16b). Consequently, the electrical resistance of heating part (16a) is also set to be substantially higher than that /5
of lead parts (16b). Consequently, when current is fed between the two ends of heater element (16), substantially no joule heat is generated at lead parts (16b), while heating part (16a) is significantly heated due to the joule heat. In this case, said heating part (16a) that generates substantial heat is almost entirely set in bridge shape on recession (13), and it extends into the space of the ink chamber, with the portion in contact with base plate (11) made as small as possible. On the other hand, lead parts (16b) are attach to the surface of base plate (11). However, the resistance of this portion is set to be substantially lower than that of heating part (16a).

With said constitution, when pulse current, for example, is fed to heater element (16), substantially no heat is generated in lead parts (16b), while substantial heat is generated in heating part (16a). As heating part (16a) extends into the space of recession (13), almost its entire length is in contact with ink liquid (15), so that the heat generated in heating part (16a) can be transmitted efficiently to ink (15). In this way, all of the heat dissipating from heating part (16a) is absorbed by surrounding ink (15), and it is

possible to avoid escape of heat by thermal conduction to base plate (11). As a result, the thermal efficiency becomes much higher than that of the prior art.

As power is fed through heater element (16) to generate heat from heating part (16a), film boiling takes place on the surface of heating part (16a), and bubbles are generated. Consequently, ink (15) is exhausted from within ink chamber (13) by a volume corresponding to that of the bubbles. In the present application example, the volume of ink chamber (13) is set to be relatively large. Consequently, the hydraulic resistance from ink chamber (13) to ink feeding channel (14) formed in the space between base plate (11) and cover plate (12) increases. Consequently, ink (15) exhausted by the bubbles generated around heating part (16a) in a thin plate shape flows in ink chamber (13) and efficiently moves toward nozzle hole (12a). As a result, ink droplet (15a) is generated. Said ink droplet (15a) is projected toward the recording medium not shown in the figure. In the state shown in Figure 2, no power is fed to heater element (16). Consequently, no bubbles are generated around heating part (16a). At nozzle hole (12a), ink (15) forms meniscus (15b) due to surface tension.

In this way, when power is fed to heater element (16) to form ink droplet (15a), when nearly all of the heating part is set in contact with the base plate as in the prior art, the heating power per dot is about 20 V x 0.5 A. On the other hand, according to the constitution of the present invention, it is only about 10 V x 0.05 A. Consequently, it is possible to significantly reduce power consumption. As a result, according to the constitution of the present invention, even with multinozzle units, power consumption is still low, and the power source unit can be made in compact, or a battery may be used as the power source if appropriate. Consequently, a portable inkjet printer is made possible.

In addition, when a recession is formed on base plate (11) to set ink chamber (13), propagation of the flow of ink in ink chamber (13) due to bubble generation to ink feeding channel (14) that has a high hydraulic resistance can be substantially stopped, so that interference between adjacent nozzle holes can

be substantially prevented, so that a high-density multinozzle constitution is possible. Also, as explained above, in the prior art, as the thermal response is slow, swift control of bubbles formation is impossible. Consequently, thermal loss and overheating lead to shortened lifetime of the heater element, which is undesired. On the other hand, in the constitution of the present invention, the thermal response is fast, and the heating temperature can be controlled finely corresponding to the environment. As a result, the thermal response increases and the lifetime is longer. Also, Figure 5 is an oblique view illustrating the overall constitution of thermal inkjet printing head (10) shown in Figures 2 and 3. It can be seen that heater element (16) has electrode parts (16c) at the ends of lead parts (16b).

In the following, an explanation will be given regarding the operation principle of the thermal inkjet printing head (10) shown in Figures 2, 3, and 5 with reference to Figures 4a-4c. Figure 4a is a diagram /6 illustrating the state before power is fed to heating part (16a). In this state, ink (15) in ink chamber (13) contacts the entire exterior of heating part (16a) in a bridge shape, and, at nozzle hole (12a), meniscus (15b) is formed due to surface tension. Figure 4b is a diagram illustrating the state right after a pulse current is fed to heating part (16a). In this case, film boiling takes place on the surface of heating part (16a), and bubbles (17) start forming. Figure 4c is a diagram illustrating the state when bubbles (17) grow the entire exterior of heating part (16a). In this case, bubbles are generated not only on the upper side of heating part (16a), but also on the lower side. The ink corresponding to the volume exhausted by generated bubbles (17) is pressed out from ink chamber (13). However, in this case, because the hydraulic resistance from ink chamber (13) to ink feeding channel (14) is relatively high, the exhausted ink flows to nozzle hole (12a), passes it through and exits to form ink droplet (15a). In this way, bubbles (17) are generated on both surfaces of heating part (16a), and their exhaust volume can be used efficiently in forming ink droplet (15a). The efficiency is thus greater than that of the prior art.

Figures 6a-6c illustrate various application examples of heater element (16). In the application example shown in Figure 6a, heater element (16) is formed by a pair of strips ($16a_1$) and ($16a_2$) separated and parallel to each other. In the application example shown in Figure 6b, heater element (16) is composed of a pair of arms ($16a_3$) and ($16a_4$). On the other hand, for the heater element shown in Figure 6c, heater element (16) is formed as H-shaped part ($16a_5$). Figures 7a and 7b illustrate application examples when nozzle hole (12a) formed through cover plate (12) is in tapered shape ($12a_1$) and flared shape ($12a_2$), respectively. The shape of said nozzle hole (12a) can be selected appropriately from these shapes corresponding to the viscosity of ink (15) and various other conditions.

Figure 8a is a diagram illustrating an application example in which instead of aligning bridge-shaped heating part (16a) with nozzle hole (12a), it is offset to the right in order to partially overlap nozzle hole (12a). In addition, Figure 8b is a diagram illustrating an application example in which bridge-shaped heating part (16a) is not overlapped with nozzle hole (12a), instead, they are set deviated from each other in the lateral direction. In all of the aforementioned application examples, heating part (16a) is offset from nozzle hole (12a), instead, it is offset from one end of ink chamber (13). As a result, the ink exhausted by the bubbles generated on the surrounding of heating part (16a) can flow more efficiently toward nozzle hole (12a).

Figures 9-14 illustrate several application examples in which heater element (16) is set in a cantilever shape instead of said bridge shape with respect to recession (13). That is, in the application example shown in Figure 9, a pair of lead parts (16b), (16b) extend from the right hand side of rectangular shaped recession (13) into the space defined by recession (13), and their tip portions are connected to form a narrow heating part (16a). Similarly, in the application example shown in Figure 10, ring-shaped heating part (16a) is set between the tip portions of first and second output gates (16a), (16b) set parallel to each other extending as a pair of cantilevers. In the application example shown in Figure 11, an H-shaped

heating part (16a) is connected between the tips of a pair of lead parts (16b), (16b). Figure 12 is a cross-sectional view illustrating the structure of a printing head having the structure shown in Figure 9 as seen from direction B-B. In this case, heating part (16a) is set aligned to nozzle hole (12a) formed through cover plate (12). However, as explained above, heating part (16a) and nozzle hole (12a) also can be offset from each other.

In the application examples shown in Figures 13 and 14, insulating layer (18) is coated on one surface of base plate (11) where recession (13) is formed. Said insulating layer (18) has cantilever-shaped supporting part (18a) formed in the prescribed pattern, and supporting part (18a) extends into the space formed by recession (13). Consequently, in this application example, cantilever-shaped lead parts (16b), (16b) of heater element (16) are coated on supporting part (18a) of insulating layer (18) to form a double-structure cantilever-shaped beam. As to be explained later in more detail, the portion extending into the space has a double structure made of substances having different linear expansion coefficients. As a result, vibration takes place due to heating of the extending portion. /7
The magnitude of this mechanical movement can be used efficiently in forming ink droplet (15a) from (15). Also, when base plate (11) is made of silicon, insulating layer (18) may be made of silicon dioxide.

In the application example shown in Figure 15, insulating layer (18) is coated on the entirety of one surface of base plate (11). On the opposite surface, a selected portion of base plate (11) is etched off until insulating layer (18) is reached to form recession (13). Consequently, the portion of insulating layer (18) exposed by recession (13) forms a diaphragm. On insulating layer (18), heater element (16) is formed, so that the heating part is set on the diaphragm. According to the present application example, in addition to the effect of volume exhausting due to bubble generation of heater element (16), as insulating layer (18) and heater element (16) are selected to have different linear expansion coefficients,

heat generation of heater element (16) leads to vibration of the diaphragm. Due to the mechanical movement in this case, growth of ink droplet (15a) may be augmented.

Figures 16-18 illustrate an application example in which sealing plate (19) that works as a spacer for defining ink feeding channel (14) that feeds ink into ink chamber (13) is included between cover plate (12) and base plate (11). In the application example shown in Figures 16 and 17, on one surface of base plate (11), a trench in a straight line channel shape is formed extending for a prescribed distance from one end of the base plate. This trench forms the ink flow channel, and a portion of it defines ink chamber (13), and, at the same time, a portion of it defines ink feeding channel (14). Said heater element (16) having heating part (16a) extending into the space in ink chamber (13) is set on base plate (11), and sealing plate (19) in a U shape is formed around the periphery of the ink flow channel. Then, cover plate (12) is set on it. With said constitution, ink chamber (13) and nozzle hole (12a) are entirely independent of each other, so that even in this case of a multinozzle structure, there is still no adverse influence from the other nozzles.

In the application example shown in Figure 18, on one surface of base plate (11), etching is performed to form recession (13), and, together with it, on the opposite surface of base plate (11), a channel trench is carved to form ink feeding channel (14). At one end, recession (13) and base plate (11) are connected through it. Sealing plate (19) that is formed in a prescribed pattern and works as a spacer is coated and set on the upper surface of base plate (11) with recession (13) formed there. Then, cover plate (12) having nozzle hole (12a) formed through it is set. On the other hand, on the lower side surface of base plate (11), back plate (20) is set to define ink feeding channel (14). Also, in these application examples, too, heating part (16a) is aligned to nozzle hole (12a). However, as explained above in the aforementioned application examples, they may also be offset from each other.

In the application example shown in Figures 19-21, base plate (11) is subjected to anisotropic etching to form a through-hole that is used as the nozzle hole. That is, in the application example shown in Figures 19 and 20, anisotropic etching is performed on base plate (11) to form tapered through-hole (11b). By means of this hole, ink chamber (13) is formed, and, together with it, a nozzle hole for injecting ink droplet (15a) is formed. Said back plate (20) is set separated by a prescribed distance from base plate (11), forming ink feeding channel (14) between them. Also, heating part (16a) is set extending into the space of recession (13). In this application example, the structure is extremely simple, and manufacturing is easy. Also, processing of heater element (16) and through-hole (11b) is integrated in a series of photoetching processes, for correct positioning alignment precision and interval formation.

Figure 21 is a modified example of the aforementioned application example. On the inner surface of base plate (11), insulating layer (18) is coated and formed, and, when tapered through-hole (11b) is formed by means of anisotropic etching, insulating layer (18) protrudes into recession (13) to form protruding portion (18a). On said protruding portion (18a), heating part (16a) of heater element (16) is coated and formed. Also, in this case, heating part (16a) is formed extending along the edge of protruding portion (18a).

As explained above, heater element (16) may be formed either as monolayer o or multilayer /8
structure. Especially, for the multilayer structure (for example, in said application example, heater element (16) is formed on an insulating layer), at least one layer has a linear expansion coefficient different from the other layers. As a result, when heating, heater element (16) vibrates, and the mechanical movement can be used effectively in generating ink droplet. In the following, an explanation will be given regarding an example of manufacturing of the cantilever-shaped heater element surrounded by an insulating layer with reference to Figures 22a-22i.

As shown in Figure 22a, on silicon or other type of base plate (11), using any well known film manufacturing method, insulating layer (18) made of silicon dioxide or the like is formed and attached, and, then, on this layer, molybdenum layer (16x), platinum layer (16y), and molybdenum layer (16z) are formed sequentially. Then, as shown in Figure 22b, on composite layer (16) composed of layers (16x), (16y) and (16z), photoresist (21) is coated. This photoresist (21) is exposed to a prescribed pattern and developed so as to form photoresist patterns (21a), (21b) shown in Figure 22c. Then, as shown in Figure 22d, plasma etching is performed to selectively etch metal composite layer (16). Then, photoresist patterns (21a), (21b) are separated to form the structure shown in Figure 22e.

Then, as shown in Figure 22f, on the entirety of the surface of the structural body, passivation film (22) made of silicon dioxide is formed and attached. Then, a photoresist is coated, followed by exposure and development to form photoresist pattern (23) shown in Figure 22g. Then, with said photoresist pattern used as a mask, wet etching is performed, and silicon dioxide is selectively etched off to form the structure shown in Figure 22h. Then, photoresist pattern (23) is peeled. Then, with silicon dioxide as a mask, the exposed portion of silicon base plate (11) is subjected to conventional anisotropic etching, so that the lower side of part (16a) is undercut to form recession (13). In this case, said part (16a) has a cantilever-shaped structure. Also, when part (16a) has a bridge-shaped structure, similarly, by means of anisotropic etching, undercutting is used. In this example, metal composite layer (16a) has a 3-layer structure made of molybdenum, platinum and molybdenum, respectively, and the periphery of composite layer (16a) is fully enclosed by underlying insulating layer (18) and passivation insulating layer (16a). However, composite layer (16a) may also have a monolayer structure as needed. Also, layer (16a) may have a structure partially covered by an insulating layer.

In the following, an explanation will be given in more detail regarding an application example when a silicon wafer is used as base plate (11) with reference to Figure 23. The upper surface of silicon base

plate (11) is (100) surface. Here, while ink flow channel (11a) is formed by means of anisotropic etching, heating part (16a) of heater is formed by means of under-etching. In this case, heating part (16a) with a bridge-shaped structure is set at an angle θ=45° so that heating part (16a) with the bridge-shaped structure is not parallel to (111) plane. In the application example shown in Figure 23, on the upper surface of base plate (11) nearly in rectangular shape, one end of ink flow channel (11a) opens to the end portion of base plate (11), and it is formed by etching to a channel shape extending in a straight line. Near the end of ink flow channel (11a), heater element (16) with heating part (16a) is set extending in a bridge shape at an angle of 45°. In addition, detecting element (26) is set parallel to heater element (16), and said detecting element (26) also has detecting part (26a) having the same bridge-shaped structure as aforementioned, as well as a pair of lead parts (26b), (26b) connected to its two ends, and electrode parts (26c), (26c). Also, one may also adopt a scheme in which detecting element (26) is formed from the same substance as that of heater element (16) at the same time. Said detecting element (26) detects variation in the electrical characteristics (such as electrical resistance) at detecting part (26a) to measure the state of the ink in ink flow channel (11a), such as ink liquid temperature and flow velocity. On base plate (11), cover plate (12) with nozzle hole (12a) formed through it is covered. In this case, it is preferred that a sealing plate of a prescribed shape be included between the two members. Also, in Figure 23, only a single nozzle hole (12a) and a single ink flow channel (11a) are shown. However, one may also adopt a scheme in which a multinozzle structure is formed by carving ink flow channel (11a) and corresponding nozzle holes (12a) in an array shape on base plate (11). /9

In the following, an explanation will be given regarding application examples in which a silicon base plate is used, and the heater and detector are in a cantilever-shaped structure with reference to Figures 24-30. Figures 24-26 are cross-sectional views taken at different sites to illustrate cover plate (12), sealing plate (19) and base plate (11) as an example of the thermal inkjet printing head of the present

invention. As shown in Figure 26, on the upper surface of silicon base plate (11), insulating layer (18) made of silicon dioxide or the like is formed and attached, and said insulating layer (18) is patterned to the prescribed shape. Also, the selected portion of base plate (11) is etched off to form the recession that defines ink chamber (13). The left end of ink chamber (13) is connected to the common ink feeding path, and, near its right end, a pair of supporting parts (18a) of insulating layer (18) protruding in ink chamber (13) in cantilever shape are formed. On these parts, ring-shaped heating part (16a) of heater element (16) and ring-shaped detecting part (26a) of detecting element (26) are formed.

In the application example shown in Figure 26, upper lead part (16b) of heater element (16) and lower lead part (26b) of detecting element (26) are connected to common lead (36). On base plate (11) having said constitution, sealing plate (19) having rectangular-shaped window (19a) shown in Figure 25 is covered. Then, as shown in Figure 24, cover plate (12) having round-shaped nozzle hole (12a) formed through it is covered. As a result, the printing head is completed. Also, when assembly is performed in this way, rectangular window (19a) is roughly around the outer periphery of ink chamber (13), so that the range of ink chamber (13) filled with ink is defined. In addition, nozzle hole (12a) is set aligned to ring-shaped heating part (16a) of heater element (16). This state can be seen from Figure 28.

The printing head shown in Figures 29 and 30 show a modified example of said printing head. In this case, on the left end of base plate (11), each ink chamber (13) has one end open to define nozzle hole (13a), or the right end of ink chamber (13) is connected to ink feeding channel (14) carved on base plate (11). In the space in each ink chamber (13), a pair of ring-shaped heating parts (16a) and ring-shaped detecting part (26a) are formed protruding in cantilever shape. Also, as shown in Figure 29, heater element (16) and detecting element (26) are shown schematically. One should pay attention to this fact. As can be seen from Figure 30, sealing plate (19) having the prescribed shape is covered on base plate (11). In addition, back plate (20) is applied on it. Consequently, in this example, base plate (11) and

back plate (20) define nozzle hole (13a) oriented in the lateral direction on one side portion of base plate (11).

In the following, an explanation will be given regarding the heater and detection driver having said heater element (16) and detecting element (26) with reference to Figures 31 and 32. As shown in Figure 31, for example, as ink (15) filled in the ink flow channel formed between base plate (11) and cover plate (12) is locally heated, bubbles are generated, and their exhaust volume is used to press ink (15) out from nozzle hole (12a) to form ink droplet (15a). At the same time, by means of detecting part (26a) of detecting element (26), the temperature of ink (15) is detected, and, on the basis of its liquid temperature information, heating driving of heating part (16a) is controlled to form optimum ink droplet (15a). For this purpose, heater driver (21) connected to heater element (16) is connected to timing circuit (23) and heater driving controller (24), and, similarly, liquid temperature detector (22) connected to detecting element (26) is also connected to timing circuit (23) and heater driving controller (24).

In this case, as described in the application example shown in Figure 26, the following scheme is preferred: heater element (16) and detecting element (26) are commonly connected to (36) to form a constitution connected to heater driver (21) and liquid temperature detector (22). Figure 32 illustrates a preferable modified example of said constitution. Also, in this case, common lead (36) may be connected to ground.

In the following, with reference to Figures 33-35, an explanation will be given in more detail regarding the following constitution: the bridge-shaped or cantilever-shaped multilayer structure of the heater element has at least one layer with a linear expansion coefficient different from the other layers. /10
As a result, the multilayer structural body undergoes mechanical vibration, and the vibration phenomenon is used to impart kinetic energy to the ink so as to contribute to formation of the ink droplet. In the application example shown in Figures 33 and 34, insulating layer (18) is coated and

formed on the upper surface of base plate (11). Said insulating layer (18) is patterned to a prescribed shape, and, together with it, the selected portion of base plate (11) is etched off to define ink chamber (13). A portion of said insulating layer (18) is made to extend into the space of ink chamber (13) to form supporting parts (18a). On insulating layer (18), heater element (16) is formed. It has a pair of lead parts (16b) set side-by-side, intermediate parts (16d) extending obliquely toward each other in cantilever shape in the space of ink chamber (13), and ring-shaped heating part (16a) connected to their tips. Consequently, said pair of intermediate parts (16d) and ring-shaped heating part (16a) form a cantilever-shaped structure, forming a 2-layer cantilever-shaped beam formed and attached to supporting parts (18a) made of an insulating substance and nearly in the same shape.

Said cover plate (12) is set above base plate (11) at a prescribed distance, forming ink feeding channel (14) between them. Said ink feeding channel (14) is connected to an ink feeding source, and is usually filled with ink. At prescribed sites of cover plate (12), nozzle holes (12a) are formed through it. As a portion of the ink is injected, ink droplet (15a) for printing is formed. In this case, if heater element (16) is made of platinum while insulating layer (18) is made of silicon dioxide, as the linear expansion coefficient of heater element (16) is greater than that of insulating layer (18), as heating part (16a) is heated, the cantilever-shaped beam is heated, and the cantilever-shaped beam bends down as indicated by the broken line. Consequently, due to this bending movement, the ink in ink chamber (13) generally flows clockwise as indicated by the arrow, and it is pressed and elongated toward nozzle hole (12a). As said cantilever-shaped beam only bends downward, it is possible to have the ink ejected from nozzle hole (12a) to form ink droplet (15a), too. However, in this case, bubbles are generated in ring-shaped heating part (16a), and its exhaust volume can be used efficiently in forming ink droplet (15a). In addition, in the application example shown in Figures 33 and 34, said ring-shaped heating part (16a) is offset to the right hand side of nozzle hole (12a). However, one may also adopt a scheme in which, as

the cantilever-shaped structural body bends upward due to heating, heating part (16a) is formed aligned to nozzle hole (12a). Also, usually, as platinum and silicon dioxide do not adhere well to each other, one may have a primer layer made of molybdenum, chromium, titanium, or the like set between platinum and silicon dioxide.

Figure 35 is a diagram illustrating an application example in which the cantilever-shaped beam bends upward under heating. That is, although the application example shown in Figure 35 has many points of structure similar to those explained in the above, it nevertheless has a special feature that sealing plate (19), which also plays the role of a spacer, is included between base plate (11) and cover plate (12). Also, in this application example, heater element (16) is formed and attached to insulating layer (18) attached to the upper surface of base plate (11) and attached to the heater element is overcoat insulating layer (22) made of the same front-edge material [sic, insulating material] as that of insulating layer (18) yet having a larger film thickness. Consequently, in principle, the cantilever-shaped beam in this application example has a 3-layer structure, with its upper layer (22) and lower layer (18) made of the same insulating substance, yet with said upper layer (22) formed thicker than said lower layer (18). Consequently, when heated by heater element (16), the cantilever-shaped beam structure bends upward as indicated by the broken line. Consequently, due to said upward bending movement, the ink is pressed out via nozzle hole (12a) to form an ink droplet. In the example shown in the figure, it is preferred that the tip portion of the cantilever-shaped beam structure be positioned near nozzle hole (12a). However, it is also possible to offset it somewhat from nozzle hole (12a). In addition, it is preferred that, in addition to the bending movement of the cantilever-shaped beam, bubbles are instantly generated on heating part (16a) and their exhaust volume also exploited in forming the ink droplet. As explained above, when heater element (16) is made of platinum and upper insulating layer (18) and lower insulating layer (22)

are made of silicon dioxide, it is preferred that molybdenum be included as an adhesive layer between them.

In the following, an explanation will be given regarding the application examples shown in /11 Figures 36-38. In the application example shown in Figures 36 and 37, the upper surface of base plate (11) is selectively etched off to form an ink flow channel having ink chamber (13) and ink feeding channel (14). The space of the ink chamber is extended, and heating part (16a) having a ring is formed in a bridge shape. One end side of ink chamber (13) is connected to nozzle hole (13a) defined on one side portion of base plate (11), and the ink droplet is ejected via it. In this application example, ink chamber (13) is formed by partially expanding the channel width of the ink flow channel. In this case, too, it is possible to realize the same effect in preventing backflow due to a rise in the flow resistance to the side of ink feeding channel (14) just as when undercutting etching is performed downward on base plate (11) as explained above. In this application example, it is possible to form the ink flow channel in a single round of etching, so that the manufacturing process can be simplified. In addition, in the application example shown in the figure, the shape tapers toward the tip, that is, from ink chamber (13) toward nozzle hole (13a). However, one may also adopt a scheme in which the transition portion has the same width or a flared shape.

As shown in Figure 37, cover plate (12) is set via sealing plate (19). Also, as a modified example of this application example, nozzle hole (13a) may be blocked, and nozzle hole (12a) is formed through the prescribed site of cover plate (12) as indicated by the broken line.

Figure 38 is a diagram illustrating another application example. In this case, a selected site of base plate (11) is etched off to form a channel-shaped trench that defines ink chamber (13). On one end of this chamber, nozzle hole (13a) is defined. In the ink chamber, a heater having ring-shaped heating part (16a) is set extending into the space. On base plate (11), back plate (20) is set via sealing plate (19) that

also plays the role of a spacer. In this application example, a trench in the prescribed shape is carved on back plate (20) to form ink feeding channel (14). This ink feeding channel (14) is connected to ink chamber (13). In this case, positioning is performed so that orifice (14a) is formed at the connecting site of ink feeding channel (14) and ink chamber (13). Consequently, the flow resistance is set high due to this orifice (14a) so as to prevent backflow from ink chamber (13). In addition, as a modified example of this application example, cavity portion (20a) may be formed as indicated by the broken line at the site corresponding to heating part (16a) of back plate (20).

In the following, an explanation will be given regarding another application examples with reference to Figures 39 and 40a-40d. In the application example shown in Figure 39, while channel-shaped ink feeding channel (14) is carved on the surface of base plate (11), ink chamber (13) in a flared shape is set. In this application example, ink chamber (13) is connected to nozzle hole (13a) defined on one end of base plate (11) via a tapered transition portion. Said heating part (16a) is set in ink chamber (13) at the position of the flared portion as a transition from ink feeding channel (14) to ink chamber (13), and ring-shaped heating part (16a) is connected to a pair of lead parts (16b), (16b).

In the following, an explanation will be given regarding the operation principle of the constitution shown in Figure 39 with reference to Figures 40a-40d. As shown in Figure 40a, ring-shaped heating part (16a) is heated, so that film boiling takes place, and growth of bubbles (17) starts. In this case, as ring-shaped heating part (16a) is positioned near the boundary between ink feeding channel (14) and ink chamber (13), generated bubbles (17) clog ink feeding channel (14). Then, as shown in Figure 40b, as bubbles (17) grow, depending on the contact angle with ink chamber (13) and the surface tension of bubbles (17), bubbles (17) expand toward nozzle hole (13a). In this case, as ink feeding channel (14) stays blocked, no pressure can be transmitted to that side. Consequently, ink (15) in ink chamber (13) is pressed out to the side of nozzle hole (13a). As no pressure is applied on the side of ink feeding channel

(14), ink (15) flows unidirectionally. As a result, ink (15) is ejected from nozzle hole (13a) to form an ink droplet.

Then, after the pulse current, as shown in Figure 40c, ring-shaped heating part (16a) is quenched by surrounding ink (15), bubbles (17) diminish instantly, and ink liquid surface (15b) is suctioned in. Then, as shown in Figure 40d, from ink feeding channel (14), fresh ink is fed into ink chamber (13), /12
and said ink liquid surface (15b) recovers to an appropriate meniscus shape under its surface tension. In this way, according to the present application example, bubbles (17) are actively grown toward nozzle hole (13a) in this constitution, so that due to growth of bubbles (17), the exhaust volume is exploited to make an effective use of the kinetic energy with directionality in forming the ink droplet.

Figure 41 is a diagram illustrating a modified example of said application example. In this case, there is ink feeding auxiliary channel (30) set as another ink feeding channel connected to the transition portion between ink chamber (13) and nozzle hole (13a). In this case, it is preferred that the flow resistance of ink feeding auxiliary channel (30) be set higher than that of the transition portion between ink chamber (13) and nozzle hole (13a). Figure 42 illustrates another modified example. In this case, flow control element (31) is set in the flow channel of the transition portion, and it is possible to set appropriate proportions for the flow of ink from ink chamber (13) and the flow of ink from ink feeding auxiliary channel (30). Figure 43 is a diagram illustrating yet another modified example. In this case, the cross-sectional area of transition portion (30a) from ink feeding auxiliary channel (30) to nozzle hole (13a) is selected larger than that of the transition portion between ink chamber (13) and ink feeding auxiliary channel (13) [sic, (30)], so as to increase the effect in suctioning ink from ink feeding auxiliary channel (30). Figure 44 is a diagram illustrating yet another modified example. In this case, transition portion (30a) is formed in a flared shape and inclines at an angle of α.

In the following, an explanation will be given regarding other application examples of the present invention with reference to Figures 45 and 46. In these application examples, the feature that directionality is imparted to generation of bubbles so as to improve the effect in forming the ink droplet is the same as that in the aforementioned application examples. In the application example shown in Figure 45, plural (four in the example shown in the figure) heating parts ($16a_1$)-($16a_4$) are set side-by-side along the ink flow channel and the longitudinal axis of ink chamber (13), and these overheating parts [sic, heating parts] generate heat sequentially toward nozzle hole (13a). As a result, the generated bubbles grow sequentially toward nozzle hole (13a), and the exhaust volume with directionality contributes to the press-out operation of the ink. In the application example shown in Figure 46, a heater H1 and thermistor T1 pair are connected in parallel, and they are connected in series to another heater H2 and thermistor T2 pair. Voltages V1 and V2, respectively, are applied on the nodes. In this case, the resistance values are selected such that T1>H1. Consequently, as current flows in H1, heat is generated, and bubbles are generated on H1. As H1 and T1 are integrated with each other, the temperature of T2[sic, T1] also rises and its resistance falls, so that current flows in T1. Then, the current in H1 falls. Because the resistance of thermistor T1 is lower by orders of magnitude, the synthetic resistance of T1, H1, T2, H2 decreases, and current flows in the path of $T_2 \rightarrow$ H2 under applied voltage V2. Here, H2 is heated, and then the current in T2 rises, and bubbles are generated on H2. As H and T are set near each other, temperature rises for them in the same way. However, as T is overheated [sic, heated] after heating of H, there is a certain time lag between them (tens of μs ~ a few msec), and the bubbles move toward nozzle hole (13a).

In the following, an explanation will be given regarding the application example shown in Figure 47. In this case, too, just as in said application example, the bubbles grow toward nozzle hole (13a). Also, according to this application example, overheating part (16a) [sic, heating part (16a)] roughly in a

V-shape and in an undulating configuration is set along the flared wall of the flared transition portion from ink feeding channel (14) to ink chamber (13). In the following, an explanation will be given regarding its operation with reference to Figures 48a-48d. As shown in Figure 48a, as a pulse current is applied on overheating part (16a) [sic, heating part (16a) to perform overheating [sic, heating], a pair of bubbles (17), (17) are generated along the walls, respectively. Then, as shown in Figure 48b, the pair of bubbles merge. In this case, merging of bubbles first takes place on the side where the flared wall connected to ink feeding channel (14) becomes narrower. Also due to the effect that bubbles tend to form in a spherical shape because of surface tension, ink feeding channel (14) is clogged. At the same time, on the side where the flared wall expands, movement of the bubbles leads to feeding of fresh ink to the heater surface. Then, as shown in Figure 48c, the fresh ink is gasified to bubbles due to overheating [sic, heating]. Because the side of ink feeding channel (14) is narrower, there is no change in the position of the bubble surface corresponding to the surface tension of the bubbles, the contact angle between the liquid and the wall surface, and the pipe resistance. On the other hand, on the opposite side, in company with the formation of a fresh bubble surface, bubbles in the stable shape shown in the figure form due to the surface tension. As shown in Figure 48d, because the pipe resistance and the resistance /13
due to nozzle is low, ink is extruded toward nozzle hole (13a). As the bubbles grow, they are cooled by the surrounding ink liquid, so that the bubbles shrink and diminish.

Figure 49 illustrates another application example. In this case, the width of overheating part (16a) [sic, heating part (16a)] is sequentially changed along its longitudinal direction so as to control the time for reaching the prescribed temperature in the longitudinal direction inside ink chamber (13) and thus imparting directionality to growth of the bubbles and to display the effect is extruding the ink no [sic, toward] nozzle hole (13a). The heater width and thermal capacity in the application example shown in Figure 49 along the longitudinal axis are shown in Figures 50a and 50c, respectively. In addition, the

time until generation of the bubbles versus the heater position is shown in Figure 50c. The operation of the application example shown in Figure 49 can be seen clearly with reference to Figures 51-53. Also, in each of Figures 51a-51c, time is taken as the abscissa, and the applied voltage is taken as the ordinate. Also, in Figures 52a-52c, the heater position is taken as the abscissa, and temperature is taken as the ordinate. In Figures 53a-53c, the heater position is taken as the abscissa; they illustrate the site where bubbles are generated. In Figures 51-53, a and b correspond to each other.

Effects

As explained above in detail, according to the present invention, it is possible to significantly reduce power consumption and to increase response speed. Consequently, it enables high-speed printing. In addition, as the structure is simple, manufacturing becomes easier, and high-precision processing can be performed easily to incorporate novel mechanisms. Especially, it is effective in constructing high-density multinozzle structures.

In the above, the embodiment of the present invention has been explained in detail. However, the present invention is not limited to these examples. Various modifications can be made as long as the technical range of the present invention is observed.

<u>Brief description of the figures</u>

Figure 1 is a schematic diagram illustrating the constitution of a typical thermal inkjet printing head of the prior art. Figure 2 is a schematic diagram illustrating Application Example 1 of the thermal inkjet printing head of the present invention. Figure 3 is a schematic plan view of the printing head shown in Figure 1. Figures 4a-4c are diagrams illustrating the operation principle of the printing head shown in Figure 1. Figure 5 is a schematic oblique view illustrating the printing head shown in Figures 2 and 3.

Figures 6a-6c are plan views illustrating the application examples pertaining to heater element (16). Figures 7a and 7b are schematic cross-sectional views illustrating modified examples of the nozzle hole. Figures 8a and 8b are schematic cross-sectional views illustrating the application examples different from each other with respect to the relative position relationship between overheating part [sic, heating part] (16a) and nozzle hole (12a), respectively. Figures 9-11 are schematic plan views illustrating heater element (16) in a cantilever-shaped beam structure. Figure 12 is a schematic cross-sectional view taken across B-B in Figure 9. Figure 13 is a schematic plan view illustrating the case when heater element (16) has a 2-layer cantilever-shaped beam structure. Figure 14 is a schematic cross-sectional view taken across C-C in Figure 13. Figure 16 is a schematic cross-sectional view illustrating an application example when a straight line ink channel is formed on the surface of base plate (11). Figure 17 is its exploded schematic oblique view. Figure 18 is a schematic cross-sectional view illustrating an application example in which an ink feeding channel is formed on the inner surface of base plate (11). Figure 19 is a schematic cross-sectional view illustrating the case when base plate (11) is anisotropically etched to form the nozzle hole. Figure 20 is its exploded schematic oblique view. Figure 21 is a schematic cross-sectional view illustrating a modified example of this case. Figures 22a-22i are schematic cross-sectional views illustrating an example of the manufacturing method of the printing head in an application example. Figure 23 is an exploded oblique view illustrating the case when detecting element (26) is set in parallel to heater element (16) used as base plate (11) composed of a silicon wafer. Figure 24 is a schematic partial plan view illustrating an example of cover plate (12). Figure 25 is a schematic partial plan view illustrating an example of sealing plate (19). Figure 26 is a schematic partial plan view illustrating an application example in which base plate (11) and heater element (16), detecting element (26) formed on it are set parallel to each other. Figures 27 and 28 are schematic cross-sectional views taken across D-D line and E-E line in Figure 26, respectively. Figure 29

is a schematic partial plan view illustrating an application example when nozzle hole (13a) is defined on one portion of base plate (11). Figure 30 is a schematic cross-sectional view taken across F-F in /14
Figure 29. Figure 31 is a schematic diagram illustrating an example of the driver of heater element (16) and detecting element (26). Figure 32 is a schematic diagram illustrating a modified example of said example. Figure 33 is a schematic cross-sectional view illustrating an application example containing cantilever-shaped 2-layer structure heater element (16). Figure 34 is a schematic plan view illustrating the positional relationship of heater element (16) and ink chamber (13). Figure 35 is a schematic cross-sectional view illustrating a modified example of said example. Figure 36 is a schematic partial plan view illustrating an application example in which the surface of base plate (11) is partially expanded in the lateral direction to define ink chamber (13). Figure 37 is a schematic cross-sectional view taken across G-G in Figure 36. Figure 38 is a schematic cross-sectional view illustrating a modified example of said example. Figure 39 is a schematic plan view illustrating an application example in which directionality is imparted to growth of bubbles. Figures 40a-40d are schematic diagrams illustrating the operation principle of said scheme. Figures 41-44 are schematic plan views illustrating a modified example in which ink feeding auxiliary channel (30) is set. Figures 45 and 46 are schematic diagram illustrating an application example in which plural heater elements are set side-by-side along the longitudinal axis of the ink flow channel to impart directionality to growth of the bubbles. Figure 47 is a schematic diagram illustrating a modified example of the scheme in imparting directionality to growth of the bubbles. Figures 48a-48d are schematic diagrams illustrating the operation principle of the aforementioned scheme. Figure 49 is a schematic diagram illustrating another modified example when directionality is imparted to growth of bubbles. Figures 50a-50c are graphs illustrating the various characteristics of the structure shown in Figure 49. Figures 51a-51c, 52a-52c and 53a-53c are graphs illustrating the operation principle of Figure 49.

Brief description of part numbers

11	Base plate
12	Cover plate
12a	Nozzle hole
13	Recession or ink chamber
14	Ink feeding channel
15	Ink
15a	Ink droplet
16	Heater element
16a	Heating part
16b	Lead parts
16c	Electrode part
18	Insulating layer
19	Sealing plate
20	Back plate
26	Detecting element
26a	Detecting part

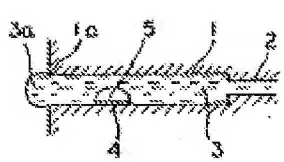


Figure 1

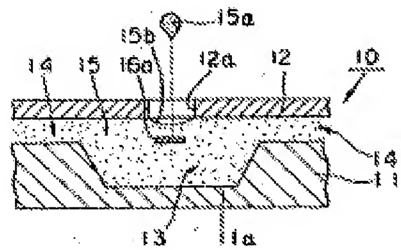


Figure 2

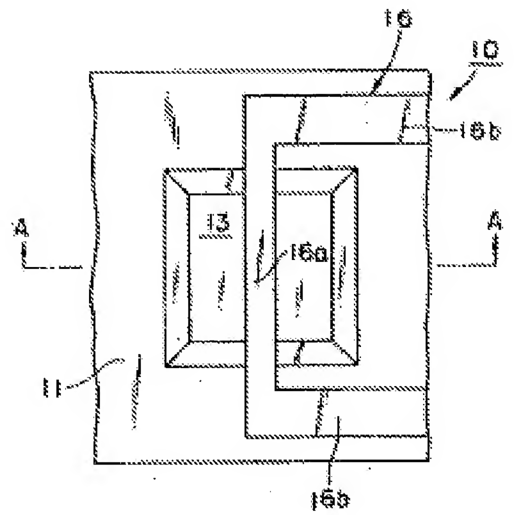


Figure 3

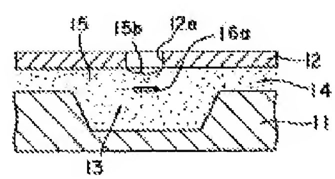


Figure 4a

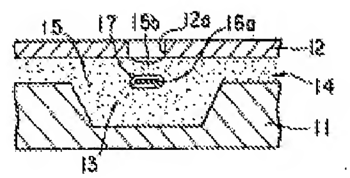


Figure 4b

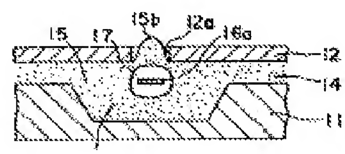


Figure 4c

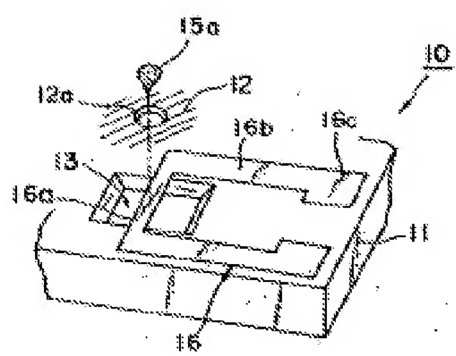


Figure 5

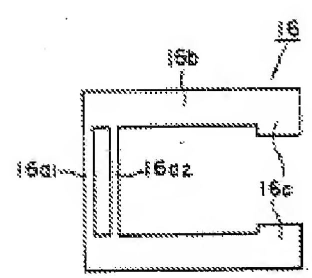


Figure 6a

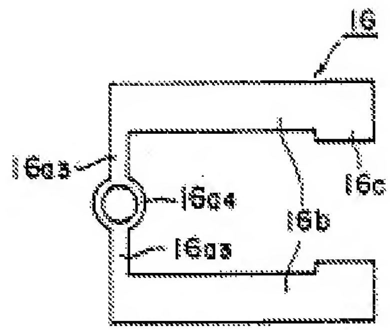


Figure 6b

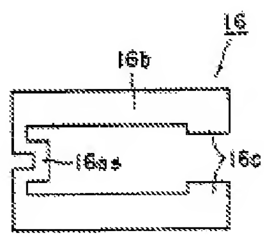


Figure 6c

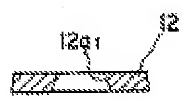


Figure 7a

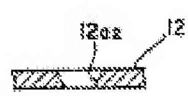


Figure 7b

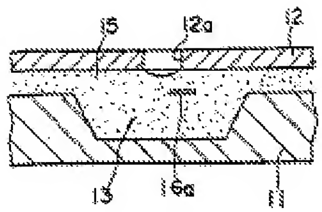


Figure 8a

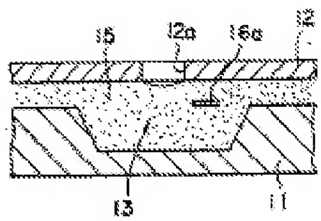


Figure 8b

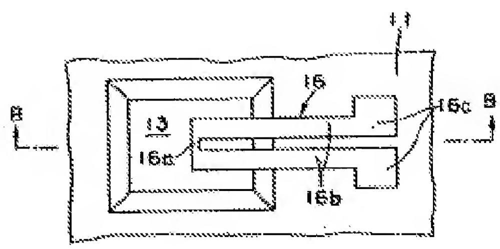


Figure 9

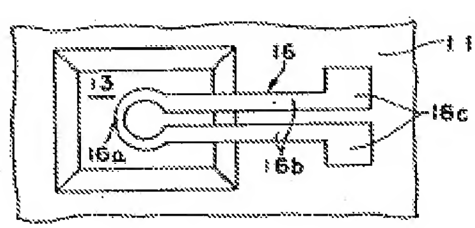


Figure 10

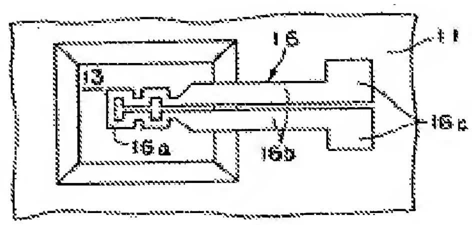


Figure 11

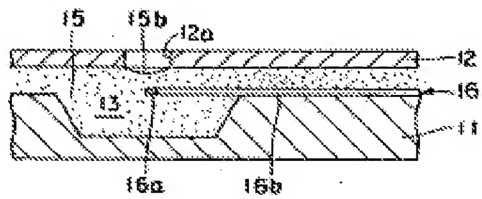


Figure 12

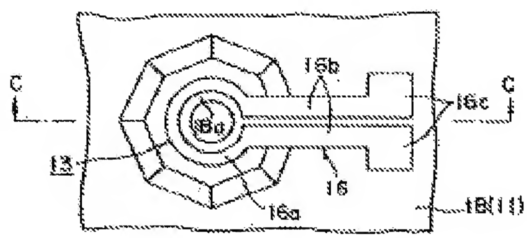


Figure 13

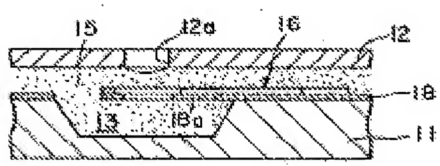


Figure 14

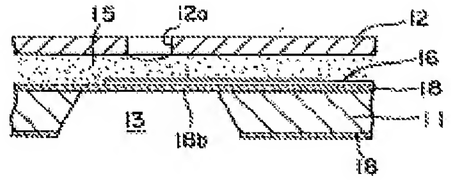


Figure 15

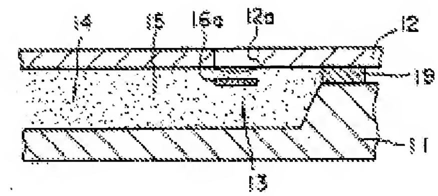


Figure 16

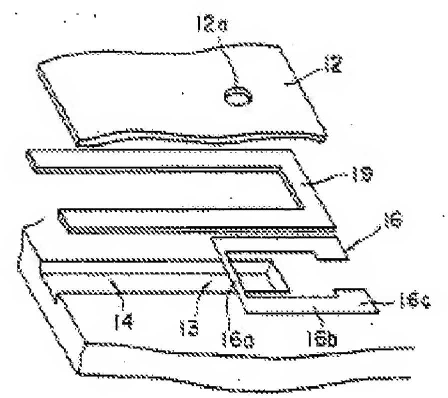
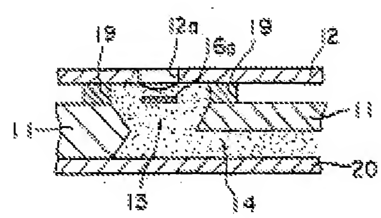


Figure 17



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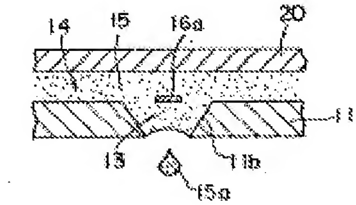

Figure 19

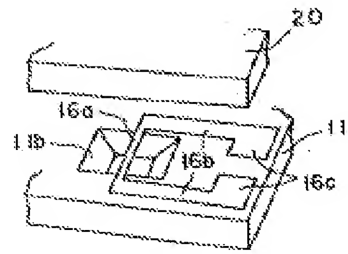

Figure 20

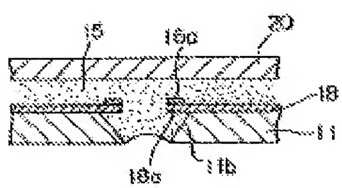

Figure 21

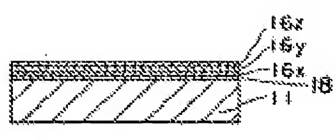

Figure 22a

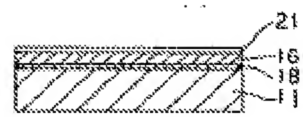

Figure 22b

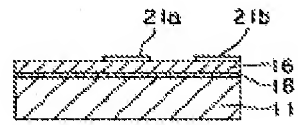

Figure 22c

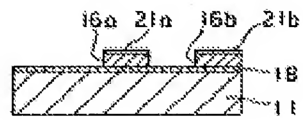

Figure 22d

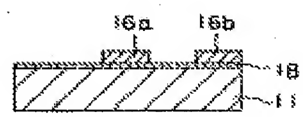

Figure 22e

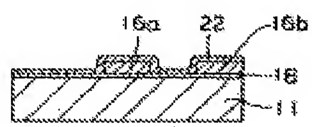

Figure 22f

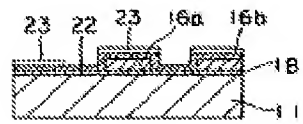

Figure 22g

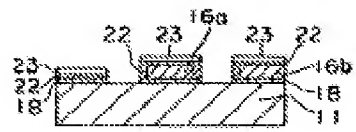

Figure 22h

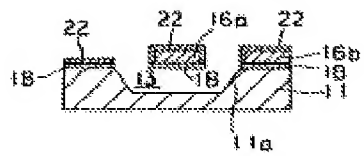

Figure 22i

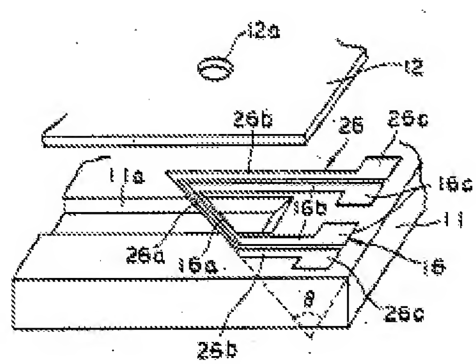

Figure 23

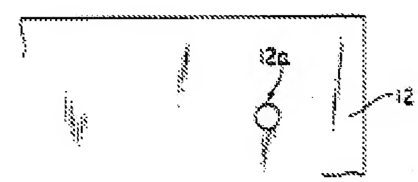

Figure 24

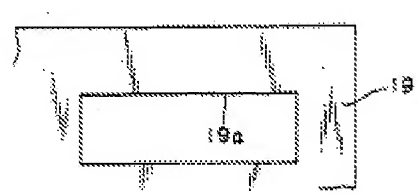

Figure 25

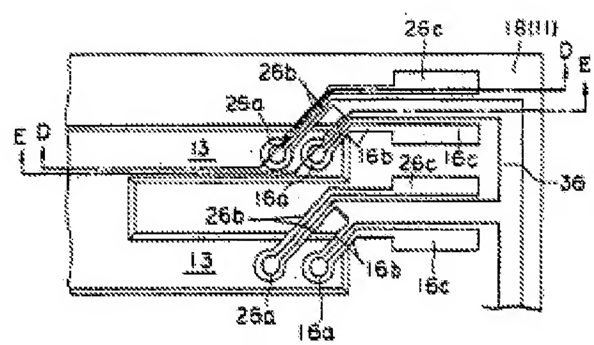

Figure 26

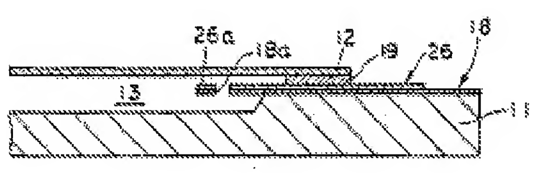

Figure 27

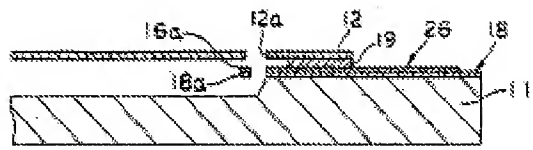

Figure 28

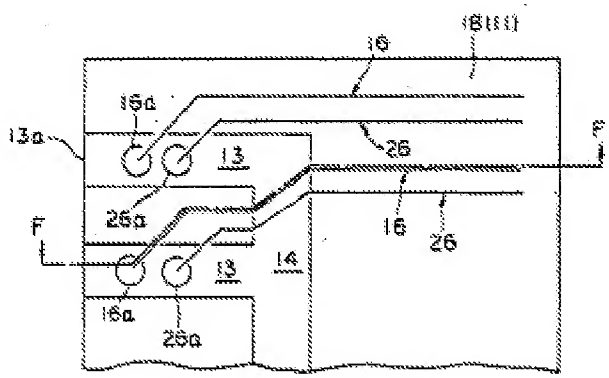

Figure 29

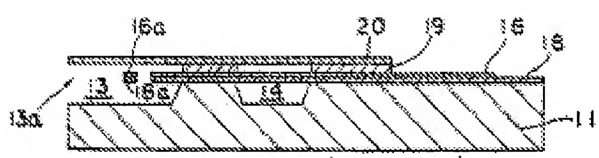

Figure 30

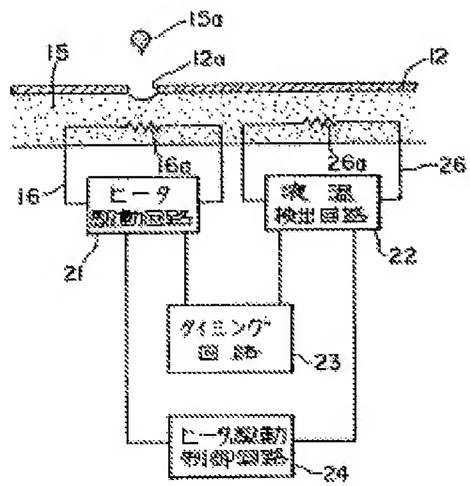

Figure 31

Key: 21 Heater driver

22 Liquid temperature detector

23 Timing circuit

24 Heater driving controller

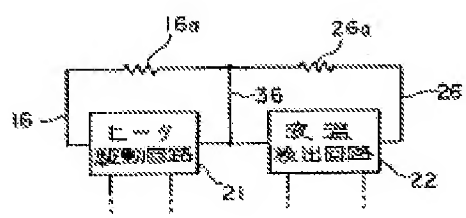

Figure 32

Key: 21 Heater driver

22 Liquid temperature detector

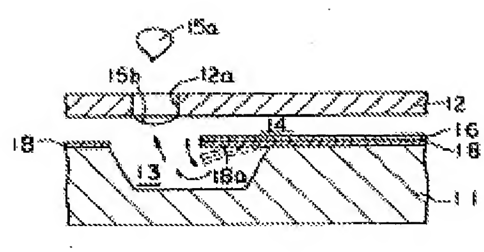

Figure 33

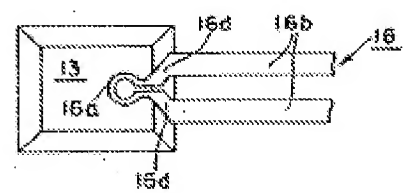

Figure 34

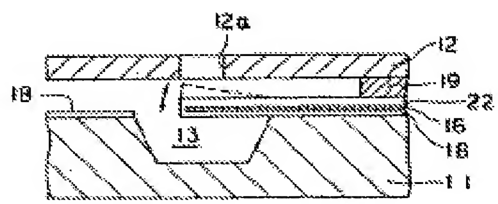

Figure 35

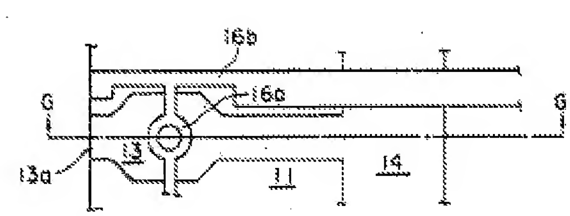

Figure 36

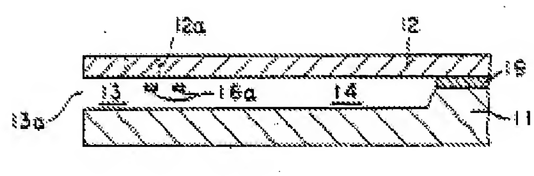

Figure 37

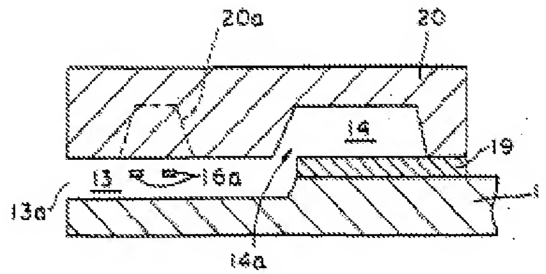

Figure 38

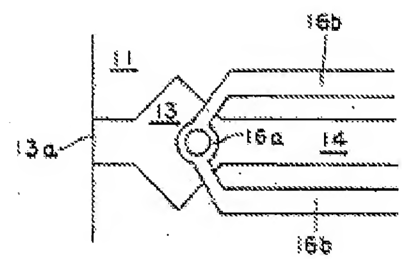

Figure 39

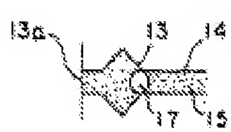

Figure 40a

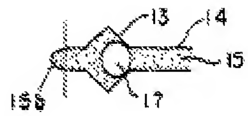

Figure 40b

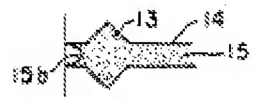

Figure 40c

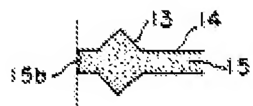

Figure 40d

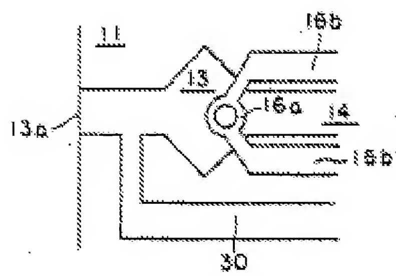

Figure 41

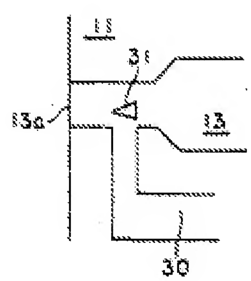

Figure 42

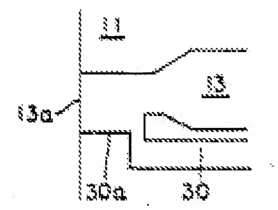

Figure 43

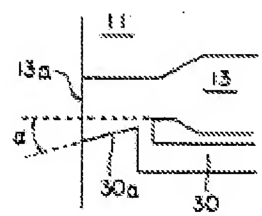

Figure 44

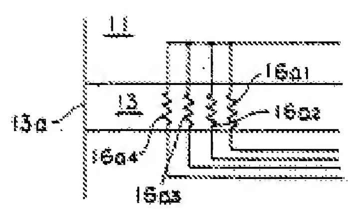

Figure 45

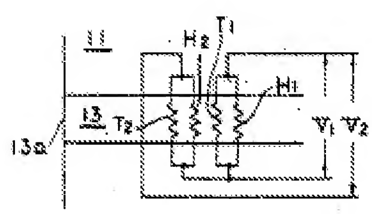

Figure 46

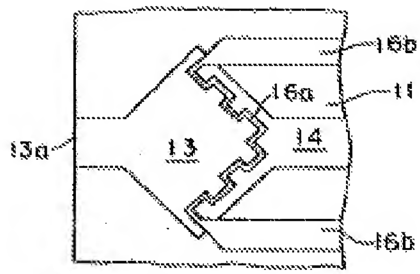

Figure 47

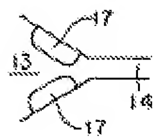

Figure 48a

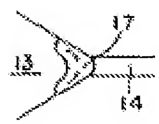

Figure 48b

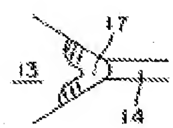

Figure 48c

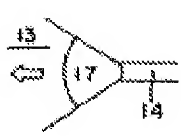

Figure 48d

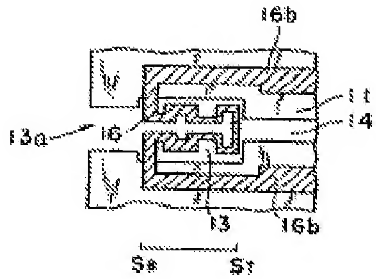

Figure 49

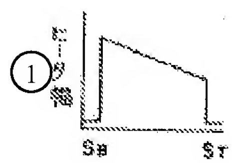

Figure 50a

Key: 1 Heater width

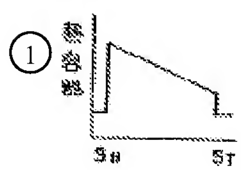

Figure 50b

Key: 1 Thermal capacity

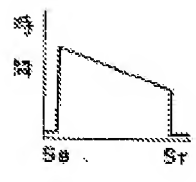

Figure 50c

Key: 1 Time

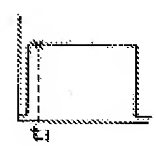

Figure 51a

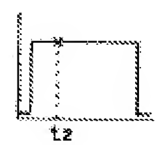

Figure 51b

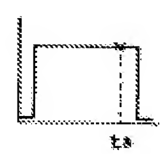

Figure 51c

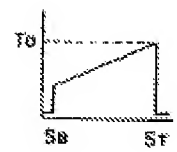

Figure 52a

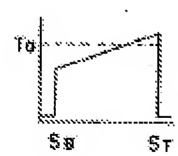

Figure 52b

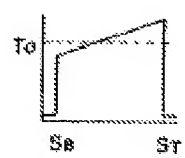

Figure 52c

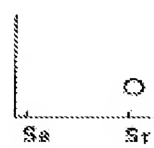

Figure 53a

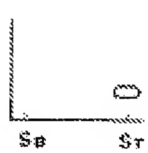

Figure 53b

Figure 53c